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Summary:

This paper proposes a new product development (NPD) process and new project leaders suitable for a modular architecture development. Based on theoretical considerations and an in-depth analysis of the common module family (CMF) architecture of Nissan Motor Company Ltd., this paper argues that a modular architecture strategy requires both a two stage NPD process and module leaders. This differs from conventional overlapping processes and heavyweight (HW) project leader. This NPD process for a modular strategy comprises two stages. First, the NPD process starts by the formulation and freezing of design rules. Second, concurrent component development activity. This sequence is mandatory, with a distinct boundary between the two stages. Formulation of design rules in the first stage requires a learning process, and an organizational arrangement promoting close coordination between technical and strategic views, enabling their integration. Also, to sustain the modular strategy, not only an HW project leader responsible for each product, but a module leader responsible for managing the modular concept are necessary. Otherwise, the modular strategy may collapse due to its fragility, even if started successfully. Based on these findings, this paper proposes the framework for an effective NPD process and project leaders in terms of product architecture.

Keywords: Modularity, Design rules, Product architecture, HW project leader, Platform leader, Module leader

1. Introduction

Despite increased attention to modularity over the past decade, an important area remains relatively unexplored. It concerns a new product development (NPD) process suitable for a modular product and project leaders required to sustain the modular strategy. In particular, the process of formulating design rules within the NPD process has not been fully investigated.

Modular architecture with standardized interfaces among different components has shown several benefits, including cost reductions, flexibility and reduced time to marketing. These advantages have given rise to the tacit assumption, that the design rule for modular architecture has been specified beforehand. Actually, firms can only fulfill the promises of modularity if they can specify architecture *ex ante* (Cabigiosu and Camuffo, 2012). The design rule, which is critically important for building modular architecture, defines how a product is divided and the interface between divided parts (Baldwin and Clark, 2000). The development of subsequent components must proceed under conditions that follow the established design rule. Despite its impact, the process of formulating a design rule has not yet been fully investigated. This paper proposes a new NPD process suitable for the modular strategy, and should therefore include the stage of design rule formulation.

Several automobile manufacturers, including Volkswagen (VW) of Germany and Nissan of Japan, have adopted the principle of modularity to meet local market needs through various combinations of modules. The goal underlying this major trend is to achieve both customer orientation and cost competitiveness in fast-growing emerging markets.

Formerly, automobile manufacturers developed cars with integral architecture, the opposite of modular architecture. As integral architecture does not require a design rule, automobile manufacturers have not had to formulate design rules. At present, however, these manufacturers have changed their product development strategy, from integral to modular architecture, and they have gone through the NPD process for modular product and design rule formulation. Therefore, to address our research questions, the automobile manufacturers have provided useful observations enabling analysis of the NPD process, in particular of design rule formulation.

This study analyzed the process by which Nissan Motors developed a modular architecture called the common module family (CMF) and the design rules for this process. Based on an in-depth case study and theoretical consideration, this study attempted to identify an NPD process suitable for developing a modular product. This analysis led to our proposal of a two stage NPD process and module leaders, differing from the conventional overlapping NPD process and HW project leaders .

The paper proceeds as follows. Section 2 reviews existing literature and the need to develop new

NPDs. Section 3 describes the research method. Section 4 illustrates the case of Nissan Motors, which have successfully adopted a modular strategy. Section 5 proposes a two stage NPD process and module leaders for developing modular products. Finally, Section 6 is the conclusion with managerial and theoretical implications.

2 Previous research and position of this paper

The present research lies at the intersection between NPD processes and product architecture. Therefore, we will first review previous research on product architecture, followed by a review of research on NPD process.

Product architecture

Product architecture has been defined as the scheme by which the function of a product is allocated among its physical components (Ulrich, 1994). Modular and integral architectures have been defined as ideal types.

Previous research on product architecture since the 1990s can be categorized roughly into two groups (Baldwin and Clark, 1997, 2000; Langlois and Robertson, 1992; Robertson and Ulrich, 1998; Ulrich, 1995; Sanchez and Mahoney, 1996; Shibata, Yano and Kodama, 2005; Shibata, 2009; Sanchez, 2008; Sanchez, 2013). Several of these studies compared the benefits of modular and integral architecture, whereas other studies investigated the dynamism of product architecture from an evolutionary perspective.

A common framework analyzing the benefits of modular architecture is based on comparisons of various examples of integral with modular architecture, such as changes in the relationships between product architecture and organization. This represents a static analytical framework, with previous research clarifying the benefits of modularity, including reductions in the costs and increases in the speed of development (Robertson and Ulrich, 1998; Ulrich, 1995; Sanchez and Mahoney, 1996; Shibata, 2008).

Much research in this category has emphasized the potential benefits of modular architecture (Sanchez and Mahoney, 1996; Baldwin and Clark, 1997). Modular architecture can be used strategically to increase product variety, improve speed to market, more radically upgrade products, and reduce costs of design (Baldwin and Clark, 1997, 2000; Langlois and Robertson, 1992; Robertson and Ulrich, 1998; Ulrich, 1995; Sanchez and Mahoney, 1996; Shibata, Yano and Kodama, 2005). The mirroring hypothesis suggests that organizations should be designed as reflections of the

architecture of the products they develop (Sanchez and Mahoney, 1996). Product architecture can then determine effective means of task partitioning and information exchange. Thus, product modularity can lead to modularity of the organizations designing and producing these products (Sanchez and Mahoney, 1996).

An analysis of the development of multi-technology products, such as aircraft engine control systems, yielded results at odds with previous research on modularity (Brusoni, Prencipe and Pavitt, 2001). Rather, to cope with imbalances resulting from uneven rates of development of the technologies of different components and unpredictable product level interdependencies, multi-technology firms require more knowledge than is required for manufacturing. Uneven rates of technological change in multi-technology products create a performance imbalance amongst components that may require an intermediate stage of integration; e.g., loosely coupled organizations coordinated by systems integrators (Brusoni and Prencipe, 2001). These arguments suggest the absence of one-to-one correspondences between product architecture and organizational architecture, and that product modularity may call for highly interactive organizational arrangements.

Regarding modular and architectural innovation, architectural innovation is defined as a change in the relationships between a product's components, and organizations are built around stable product architectures. It has been postulated that the product architecture defines information processing capabilities, communication channels, and information filters within the organization. (Henderson and Clark, 1990). These contributions have highlighted the managerial implications of modularity in products and organizations.

Other research was performed to understand the logic and evolution of product architecture. The computer industry was analyzed in detail to determine the evolutionary processes in this industry as a function of the complex adaptive system framework paradigm (Baldwin and Clark, 2000). Several evolutionary tracks are created in an object with modular design, without the object controlling the evolutionary tracks. This is due to the individual effects of six operators (e.g. splitting) on each module, perhaps explaining the rapid and various evolutionary tracks within the computer industry after emergence of the modularized IBM System/360.

Other research based on an evolutionary perspective includes discussions of a dynamic shift in architecture (Chesbrough and Kusunoki, 2001) and of module dynamics (Shibata, 2009). These studies showed that product architecture moves gradually, from integral to modular, later returning from modular to integral after technical breakthroughs of the system. Thus, existing studies of product architecture can be categorized into the above two groups.

However, another important area remains relatively unexplored, identifying the optimal NPD process, including design rule formulation, suitable for developing modular products. Therefore, we will review existing literature on the NPD process and discuss the necessity of building a new NPD process for a modular strategy.

New product development (NPD) process

Effective NPD processes are characterized by overlapping process (Takeuchi and Nonaka, 1986; Clark and Fujimoto, 1991), in which the same tasks are completed by multiple entities while information is shared among the various involved departments.

In overlapping, the design specifications are not fixed during early stages of development. Rather, the final specifications are determined through close coordination among various departments once development begins. This process has been called the rugby style of development because, like rugby, the development process will be performed by multiple departments that share information and tasks.

Leading companies have used the overlapping process to maximize reliability and delivery. The overlapping process requires an organization capable of managing complicated information flow among departments. Organizationally, Japanese companies have used a heavyweight project manager system to manage the complexity of information sharing (Clark and Fujimoto, 1991). Actually, Japanese carmakers have implemented internal heavyweight project manager systems using different names. For example, Toyota calls a heavyweight project manager a chief engineer. Companies in other countries have also tried to learn and implement these practices.

Overlapping, however, is not always successful, with its effectiveness depending on the industry. For example, overlapping was reportedly unrelated to the product development process in the computer industry. Rather, technology integration has been found to affect performance in the mainframe computer industry (Iansiti and West, 1997; Iansiti, 1998). These differences are due to rates of change in the computer and automobile industries, with the former changing more rapidly and the latter remaining more stable (Eisenhardt and Tabrizi, 1995). Overlapping is considered ineffective in the fast-changing computer industry, with speed of market changes being one factor influencing the effectiveness of overlapping.

Aside from the speed of market change, this paper explores another factor influencing the effectiveness of overlapping process and HW project leaders. It sheds light on the importance of product architecture to an effective NPD process, and suggests an effective NPD process may be reliant on the product architecture, integral (non-modular) or modular architecture. This paper

proposes a new NPD process and new project leaders suitable for modular architecture. Through these considerations, we aim to advance the understanding of effective NPD process from the perspective of product architecture.

New type of NPD process and project leaders for a modular strategy

In overlapping processes, design rules, including interface rules, are not fully specified or fixed during the early stages of development. Thus, frequent interface changes are likely to be made by the various component development groups. Conflicts among component groups over component interfaces are likely to become common. Management of these conflicts will require heavy weight (HW) project managers to play important roles during overlapping NPD processes. These features of an overlapping process are not suitable for the development of modular products. An overlapping process and HW project manager will be more effective for non-modular than modular product architecture. Thus, the development of modular products requires new NPD processes, including design rule formation processes, which differ from overlapping processes.

Design rule matters for modular architecture. The design rule defines the division of a product and the interfaces among these divisions (Baldwin and Clark, 2000). For modular architecture, the design rule indeed matters, and formulating it requires a learning process. In determining how to divide a product system into modules, there are, in principle, innumerable choices. Thus, it is not an easy matter to determine the method of division, or the design rule of modularity, that will optimize the expandability and reliability of the system as a whole. Simply dividing the system into modules is insufficient. Many combinations must be considered when creating correspondences between functional and structural elements and in grouping structural elements. Accordingly, the selection of a method of division and certain combinations from among the available choices will probably lead to differences in product functionality and performance. Furthermore, the various individually designed subsystems must function well as an entire system after integration.

Therefore, design rules must be formulated to optimize the overall performance and reliability of the entire product system. Companies must determine the divisions that are needed, as well as their interfaces, to effectively accomplish these goals. Therefore, the process of design rule formulation is a type of learning process, and learning about product design occurs in the midst of this trial and error process (Shibata and Yano, 2003). Thus, design rules will be established through accumulated knowledge, experience, and expertise of a company. The process involves organizational decision making as well as organizational learning. Only after completion of the design rule can the

concurrent developing of components commence. The task of design rule formation is therefore completely different from that of component development. The nature of formulating design rules is different from that of developing components concurrently.

Therefore, this paper proposes a two stage NPD process suitable for modular products, where the stage of formulating the design rule is clearly separated from the stage of component development. In addition, maintaining modular architecture as the product develops with variation is a different story from commencing modular architecture development. Even if a modular strategy has started successfully, its continued effectiveness requires project leaders in addition to the traditional HW project leader responsible for each product. Just one HW project leader is insufficient for an effective modular strategy. Therefore, this paper emphasizes a shift of importance in project management style from HW project leaders to ML (module leaders) for modular products to maintain the modular concept in developing product variation.

3 Research Method

3.1 Case study and data

Due to the exploratory nature of this study, a qualitative, in-depth case study methodology was adopted, enabling the collection of comprehensive data and the generation of theoretical findings that could not be derived satisfactorily from existing theory. The development of theoretical insights and findings based on case studies can result in initiation of the study as close as possible to the ideal of no theory under consideration and no hypothesis to test.

Case studies have been shown effective in assessing the relationships between causes and results of business phenomena and their appropriateness from multiple perspectives and interpretations (e.g., Eisenhardt, 1989; Pettigrew, 1990; Yin, 1994). Case studies can provide deep insights based on objective qualitative information and researchers' subjective interpretation of individual cases, insights not provided by statistical analyses. Case studies not complementing generalities based on statistical methods can help in constructing novel, creative theories.

The case study described in this paper focuses on research questions related to the NPD process of developing CMF in a company. It provides in-depth analysis and observations regarding how that company developed a modular product. This case study of Nissan is based on the authors' interviews with a number of company executives, including one board member and five officers, as well as on internal information and data (including corporate information in the public domain).

Five in-depth, semi-structured interviews, each lasting about two hours, were conducted during 2012 and 2013. Interview data were complemented by follow-up communications via telephone and email. The case of Nissan CMF was constructed using data from interviews, published product literature, and Nissan's technical documents. For validation, a draft of the case was circulated to the individuals interviewed, who made corrections where appropriate.

3.2 Framework of case analysis

This paper focuses on Nissan CMF because it achieved modularity between two companies with different histories and traditions, Renault and Nissan. It is difficult to promote modularity within one company, so modularity between different companies will be far more difficult and complex. CMF is an extreme case in this sense, providing the essence of the mechanism behind superficial phenomena.

The purpose of this paper is to identify and develop new NPD processes for the development of modular products. The framework of analyzing the NPD process for the CMF therefore has two viewpoints. The first is the stage of formulating the design rule, when compared with the stage of component development. That is, should there be clear boundaries between the design rule formulation and the component development processes? The second viewpoint is the organizational viewpoint regarding the process of formulating a design rule. That is, how should the process be divided among related departments and who should lead the process?

Based on a case analysis of CMF and theoretical consideration, we will build an NPD process suitable for the development of modular architecture. Modular architecture here refers to a closed module, wherein the design rule is proprietary within a company, as opposed to open modules like personal computers. However, the two are the same in that both require clear design rules.

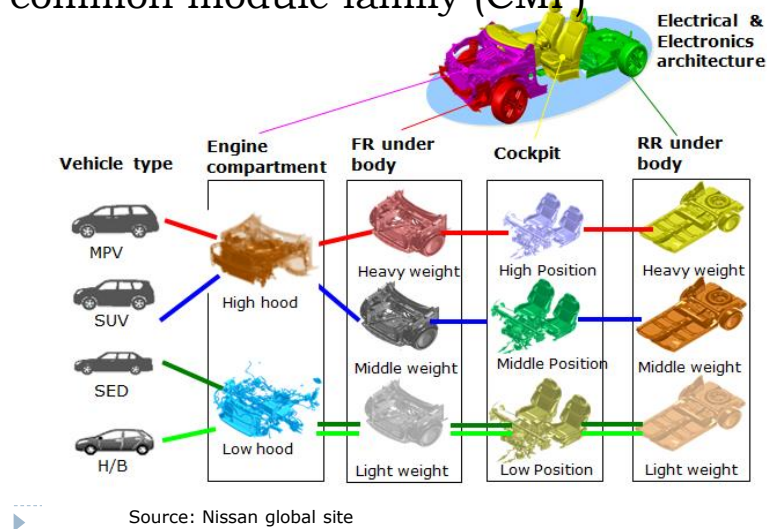
4 Case study: NPD Process for the Nissan CMF

On February 27, 2012, Carlos Ghosn, the President and Chairman of Nissan, introduced the 4+1 CMF to the media as a fundamental change to the vehicle design concept.

"4+1" means four structure modules (engine compartment, front underbody, cockpit, and rear underbody) and one electrical module (electrical/electronics architecture), which are called big modules. The interface rules between pairs of big modules are formulated from both a physical standpoint (including position, dimension and form, collision safety, and the input/output of sound, vibration, and heat, among others) and an electrical standpoint. Each of these big modules has a

number of design variations for a mid-class vehicle, specifically two types of engine compartments, three types of front underbodies, three types of cockpits, and three types of rear underbodies. Thus, there are theoretically 54 combinations of these four big modules ($2 \times 3 \times 3 \times 3 = 54$), resulting in 54 different vehicles.

Fig. 1. Conceptual diagram of common module family (CMF)



In contrast, the electrical/electronic architecture uses one type of hardware and one type of software for all variable parts.

The CMF was designed to generate vehicles with different designs and functionality, while promoting standardization, and to create an optimum balance between product variation and volume efficiency. If component-sharing creates significant cost savings, funds can be invested in environmental and safety measures, which will increase the competitiveness of this product in the future. Moreover, the application of new technology can enhance developmental efficiency of many types of vehicles, a process that has to date been applied only to luxury cars.

Previously, automobile manufacturers standardized components used on the same platform (chassis). However, this approach has limitations. In developing the CMF, Nissan aimed to standardize components for different platforms (cross-platform), effectively eliminating the platform concept. In designing the CMF, components were classified not by platform but by the element in which the component could vary. For example, engineers could first consider whether weight or other elements should vary. In the former case, they would consider a basic design, in which components could vary by weight. As a result of the CMF, the compatibility between Nissan and Renault

drastically increased, from 6% to 53%, based on the prices of the components, reducing component costs by 30%. This was considered more remarkable because it did not impair product variation when compared with conventional methods.

The project of developing CMF officially began in September 2009, with the first year devoted to formulating the design rule. Once the design rule was established, the project shifted to concrete product design at the end of 2010. The first CMF-based mass production started in autumn 2013 with the launch of the new X-TRAIL. A total of 1.6 million vehicles, consisting of two types of Nissan vehicles, including the X-TRAIL, and 10 Renault models, were introduced to the market sequentially. The designs of all of these new models were based on different combinations of the five big modules of the CMF. In the future, Nissan will apply the CMF to all vehicles, except those that require a specific manufacturing process. The next Section describes the CMF developmental process and organizational arrangement.

4.1 Establishing an interface between big modules

Because the goal of the CMF is the development of cars using combinations of 4+1 big modules, one of the important design rules concerns the compatibility of the physical and electrical interfaces between pairs of modules, a process developed sequentially from September 2009 to the end of 2010. The physical interface includes the widths of the lower dashboard and floor, the points of installation of the air conditioning unit and the front seat rail, and the penetration position of the lower dashboard, among others. Similarly, the electrical/electronic interface includes assigning functions to the controllers and assigning controllers to a network, which triggers functionality, and the methods of supplying electricity to the body control module (BCM) and other components. These two types of interface rules were determined sequentially between each pair of big modules.

One of the most important factors in this process is accumulated knowledge and experience of “simulation technology”, with the most difficult being the collision experiment. However, as Nissan has accumulated experimental data over many years, there is little difference between collision experiments using actual vehicles and the results of computer simulation, making it possible to fine tune designs once the big modules are combined. This high correlation between real and simulated data enabled collisions to be simulated, a process previously difficult to perform. This cutting-edge simulation technology contributed significantly to improvements in the design capacity of Nissan. According to Nissan, without the simulation technology, it would not have been possible to formulate a design rule for CMF.

The procedure used to formulate interface rules between big modules began by setting a target performance value for each vehicle. This was followed by changes in the boundary and synthesis conditions of the interfaces between the big modules. Simulations were used to determine the conditions required to reduce the interference ranges between modules as much as possible to achieve the vehicle's target performance. Adjustments were made based on feedback and the simulation was repeated. These cycles were repeated until target performance was reached. According to Nissan, simply integrating the big modules will lead to completion of about 80% of each vehicle.

4.2 Strategic issues of design rule

While the interfaces between big modules were being developed, solutions to the strategic issues of design rule within the big modules were promoted. The most difficult issue was determining where and how common parts and variable parts should be separated within a big module, a problem that must be resolved by formulating the design rules for each big module. This is more than a technical issue, as it requires strategic considerations of various conditions.

The first strategic issue arises from differences in market requirements; for example, requirements may differ in Asia and North America. Thus, there is a risk that sharing components sacrifices some market requirements. However, without component-sharing, it would not have been possible to efficiently manufacture an appropriate number of vehicles. This requires determination and promotion of the most appropriate level of component-sharing. Similarly, component sharing must avoid damaging the brand image of each model vehicle, an issue that arises even for component-sharing within a company.

The second strategic issue arises from the differences in technical policies between the two manufacturers. Nissan calls its basic policy on the technology resulting from its accumulated historic experiences the Technical Policy. As both companies have different histories, it became difficult to judge which parts should be common to both and which should vary. In the case of CMF, the difference in technical policies became critical for promoting component-sharing between Nissan and Renault.

For example, the design method aimed to avoid accidents and to ensure strength and the absorption of collision energy depended largely on each company's technical policy. Similarly, each company had different policies for the placement of the AC compressor control. At Nissan, this unit was controlled by an electronic control unit, whereas, at Renault, this unit was controlled by another unit. This difference depends largely on policy rather than technology. Companies with different histories

will develop different policies, which are reflected in differences in design activity and the products themselves.¹

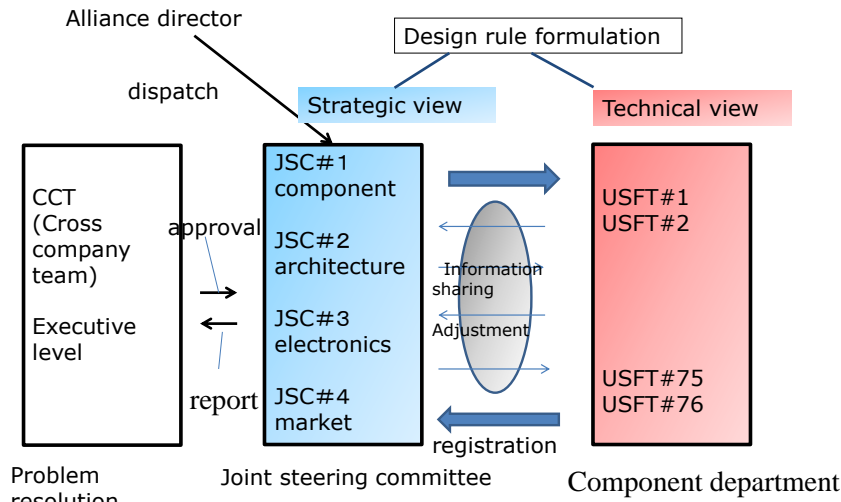
Thus, to promote component-sharing between Nissan and Renault, the differences in technical policies had to be overcome, in addition to resolving issues caused by differences in market requirements. These are beyond the technical perspective. Rather, they concern strategic perspectives related to prerequisites in starting design activity. Nissan termed an issue obstructing component-sharing a Road Block (RB). The CMF project formulated a basic policy that actual component developments could not begin until all RBs were completely solved. RB resolution was set as a top priority in CMF project. Figure 4 shows that the 859 RBs at the end of 2009 decreased rapidly within one year.

4.3 Organization and Process to Solve Road Blocks

Organizationally, the design department alone could not resolve RBs, because the technical capacity of that department was not sufficient for resolving strategic issues. Nissan developed a new organizational system, in which both technical and strategic (market requirement and technical policy) perspectives were incorporated to resolve RBs. Figure 2 shows the essence of this organizational system, which became a strong driving force promoting RB resolution and formulating design rules. The most important feature of the system was the introduction of both the technical capacity of the upstream strategic functional team (USFT) and the strategic capacity of the Joint Steering Committee (JSC). As the organizational system to resolve these RBs, the close cooperation and adjustment between the JSC and the USFT enhanced the role of the component design department.

The JSC was tasked with resolving RBs at the General Management level of both Nissan and Renault, and appointed the appropriate team members to deal with the issue at hand. Various types of technology, knowledge, and know-how were required to solve the more than 800 RBs. Therefore, the companies established a flexible organization, enabling suitable members to come together according to the contents of an RB.

Fig. 2. Organizational system for formulating design rules



The USFT is a component design department that develops products and to which work was assigned relative to each component system, such as seats and steering. The total number of components per car was approximately 30,000, divided into 76 component systems, with one USFT assigned to each system. As each USFT has approximately 20 members, about 1,500 persons, all members of the USFTs, were involved in component design.

In addition, the official reporting channel shown in Figure 2 contributed to resolving RBs. The JSC, in coordination with the USFT, provided monthly progress reports on RB resolution to the cross company team (CCT), a management team composed of executives, including Vice Presidents, which promoted RB solutions. Simultaneously, the JSC consulted with the USFTs about unresolved issues and other difficult matters, seeking direction in some cases.

The process of formulating a design rule within each big module started with collecting as many issues as possible obstructing component-sharing from the requisite USFTs. Each USFT had strong incentives to promote component-sharing through the modular concept of CMF.

The first step in promoting component-sharing was identification of the obstructing factor. All members of the USFTs were asked about impediments to standardizing the components and why sharing was difficult. By November 2009, this process had identified 859 issues obstructing component-sharing. These issues were registered in a database of RBs to resolve. The 859 RBs were broadly divided into four groups of problems; for example, those related to mechanical architecture or market requirements, and assigned to four JSCs. Issues related to components were assigned to

JSC #1, issues related to mechanical architecture to JSC #2, issues related to electrical/electronics architecture to JSC #3, and issues related to market and product requirements to JSC #4. Each JSC included six General Managers, three each from Nissan and Renault, and administered by the Alliance Directors. These JSCs were tasked with solving the RBs reported by the USFTs. As RBs could not be resolved only by USFT employees with technical capacities, the JSC tried to apply strategic perspective, such as market and technical policy, to RB resolution. If necessary, a JSC asked other department to collect new, experimental data and conduct additional market research.

Effectively solving RBs required close cooperation between the JSC and USFT. The component layout issue provides an appropriate example. The body control module (BCM), which controls power windows, had been installed in different places in different model vehicles. This resulted in diverse types of wire harnesses, the cable used to connect the BCM with other devices in the car. This problem could be solved by aligning the technical policy about the layout of BCM, which would standardize the wire harness. However, the USFT responsible for developing the wire harness could not solve the issue of the BCM layout. Rather, the JSC, which has strategic perspective, led the work to standardize the BCM layout, making it possible for the USFT to develop a standardized wire harness based on the standardized BCM layout. Decisions about standardization of the BCM layout and wire harness required frequent information sharing and adjustment between the JSC and USFT. Therefore, Nissan developed an organizational system that enabled close cooperation and adjustment between JSC and USFT (Figure 2).

Fig. 3. Process of resolving road blocks

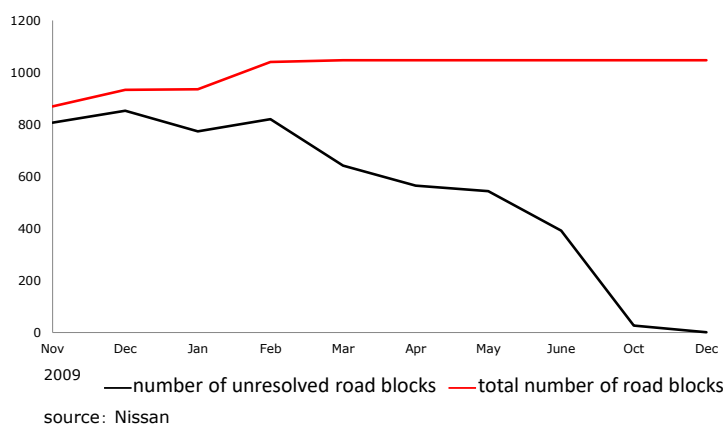
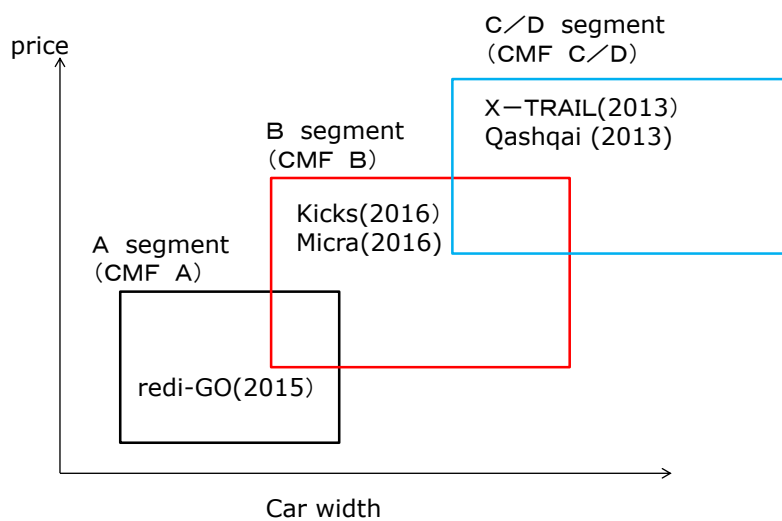


Figure 3 shows that the 859 initially identified RBs were resolved within one year. In this way, Nissan made every effort to resolve all RBs before starting actual component development.²

4.4 Project leaders for maintaining CMF modular concept to all of market segment:

CVE (Chief vehicle engineer), APFL (Alliance Platform leader) and ABML (Alliance big module leader)

Fig.4 Applying CMF architecture to all of market segment in Nissan



4

After solving all RBs and formulating design rules in the first stage, Nissan started producing actual components and integrating them into each vehicle in the second stage. Producing a CMF vehicle requires a person to coordinate the combinations of these big modules. Combinations of multiple big modules must follow interface rules to ensure the integrity of each car for the customer. The person is called Chief Vehicle Engineer (CVE) in Nissan, corresponding to an HW project leader.

CVEs are responsible for the technical performance of each completed vehicle, and therefore focus on each vehicle type to maximize its value while differentiating it from other types. It is no wonder that a CVE might have a natural tendency to prefer customized components instead of standardized components to generate maximum performance and maximum value in their particular vehicle. In this way, the desire of a CVE to develop as much value in his car as possible may tend to

sacrifice component sharing with different types of cars, which must ultimately risk destroying the CMF modular concept.

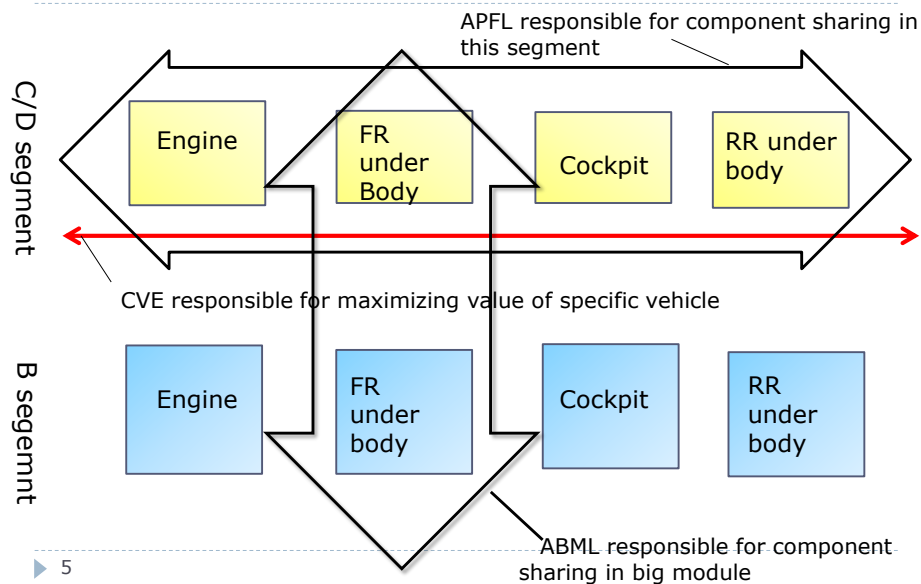
The first CMF-based car commercialization started in 2013 with X-TRAIL targeting C/D market segment. Until 2016, Nissan applied the CMF concept to market segment B and A beyond segment C/D, and introduced six types of vehicles sequentially. Figure 4 shows in detail that two vehicle types in segment C/D, two in segment B, and one in segment A have been introduced to the market.

In 2015, two years after introducing the first CMF-based mass production car, Nissan established new posts of two project leaders described in Figure 5. Because Nissan noticed the necessity that keeping the CMF concept requires not only a CVE but also other project leaders responsible for managing design rules and component sharing beyond each specific vehicle in applying the CMF concept to other market segments than C/D. As shown in Figure 5, both APFL (Alliance platform leader) and ABML (Alliance big module leader) were additional project leaders to CVE corresponding to HW project leaders. To maintain the CMF modular concept, modularity needs to be managed in two dimensions, namely dimension of market segment and dimension of big module.

In 2015, Nissan created new positions tasked with the responsibility of ensuring maximum component sharing as possible in each market segment. Nissan called this position Alliance platform leader (APFL). There are three classes of CMF corresponding to different market segments CMF A, CMF B, and CMF C/D, respectively. Each APFL is responsible for managing modularity in their market segment. For instance, APFL for segment B is responsible for enforcing design rules and maximizing component sharing for not only Micra but Kicks in Figure 4.

Similarly, in 2015 while applying the CMF concept, Nissan noticed a growing possibility that design rules and component sharing within each big module might be at risk of sacrifice with strives for product variation. So, Nissan introduced the role of ABML (Alliance big module leader), whose responsibility was to ensure the design rules were followed and maximize component sharing within each big module. There are four big modules in CMF architecture, namely engine compartment, FR under body, Cockpit, and RR under body. Therefore, Nissan established four ABML each responsible for one big module.

Fig.5 Project leaders for keeping CMF modular concept



5 Discussion

Although there are limits to what can be inferred from analysis of this single case, the wealth of detail available in this case should provide empirical findings relevant to the NPD process of developing modular architecture. Based on in-depth case analysis, we wish to discuss three contributions mentioned below.

5.1 Two stage NPD process for modular architecture development

This case revealed that Nissan first formulated design rules by the end of 2010 before beginning concrete product development. In fact, their CMF first established design rules, such as interfaces between big modules, and considered appropriate boundaries between common and variable parts. At the end of 2010, when the design rules were formulated through resolving RBs, Nissan started designing actual components. This NPD process was a completely new approach for Nissan, when it adopted this CMF project. Through accumulated experience and knowledge of past projects, Nissan had learned that conventional and overlapping NPD processes were not appropriate for developing modular products.

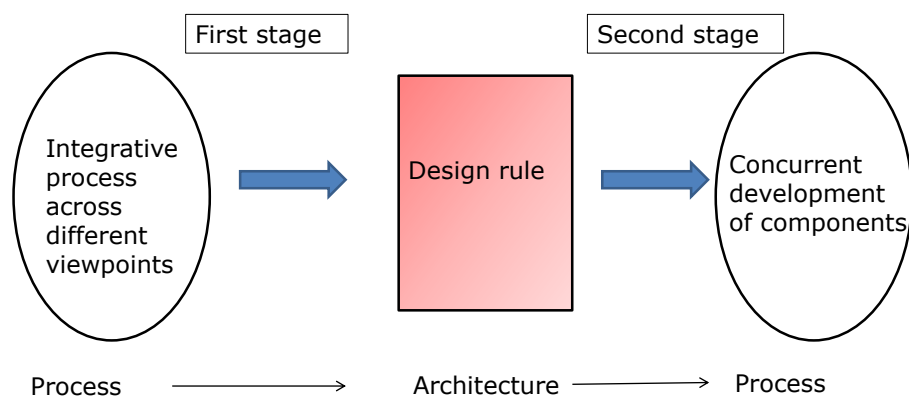
Analysis of this CMF case and theoretical considerations indicate that the new NPD process was suitable for developing modular products. This process consists of two different tasks, design rule formulation, followed by concurrent development of components according to the established design

rule (Figure 5). This sequence should be strictly observed during the two stage NPD process.

The design rules can have a critical effect on the success or failure of modularity, since subsequent concrete design activities are constrained by the design rules. Successful modularity therefore requires that concrete product development begins only after the design rules are set. Changing the formulated design rules during the component development process will result in an open-ended development project and the consumption of management resources. This pattern of failure has been frequently observed in unsuccessful modularity projects (Sanchez, 2013). Therefore, a two stage NPD process should draw a clear line between design rule formulation and component development.

During the second stage, the component development process, each component team will be able to focus its activities on individual components, without paying attention to other components. This requires the design rule to be fully specified and fixed, providing a stable environment that it enables all subsystems and components to be developed concurrently (Sanchez, 2015). Proposing this new NPD process for a modular strategy is this paper's first contribution to existing research on modularity.

Fig. 6. Two stage new product development process (NPD) for modular architecture



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5.2 Design rule formulation as a learning process

In the two stage NPD process, the first stage consists of decision making about the design rules.

Based on the CMF case, we will determine the nature of design rule formulation, followed by the organizational process of developing a design rule.

As this case showed, the CMF project had to solve two kinds of issues, those requiring a strategic perspective for RB resolution, such as adaptation to different market requirements and different technical policies, and those requiring organizational technical capacities, such as simulation technology. Even if strategic perspective issues can be solved, excellent component-sharing will require the technical capacity to perform concrete product development. In contrast, even at a high level of technical capacity, excellent component-sharing comes only through the resolution of RBs from a strategic perspective.

Theoretically, this paper suggests that design rule formulation needs more than a technical perspective. Excessive component-sharing sacrifices adaptation to different market requirements, whereas insufficient component-sharing does not produce volume efficiency. Therefore, design rules will have to balance market requirements and volume efficiency. This task cannot be resolved only from a technical perspective; rather, it requires a strategic perspective. In the case of CMF, there were two types of strategic issues, adaptation to different markets and adaptation to different technical policies without sacrificing volume efficiency. Design rules will therefore be influenced by two factors, the resolution of both strategic and technical issues.

Conventionally, design rule formulation was regarded as a purely technical issue, resulting in development tools such as Design Structure Matrix (DSM), based on a technological viewpoint (Baldwin and Clark, 2000). DSM is a design method to determine boundaries between subsystems, such as components and tasks, by focusing on the strength of interdependent relationships. DSM tries to minimize the complexity regarding the technical interdependence between subsystems, but does not consider needs of different markets. Therefore, DSM cannot provide the strategic perspective necessary for design rule formulation, requiring complementation by organizational arrangement.

Understanding this nature of design rules, Nissan established a new organizational system to develop an effective design rule. Indeed, the CMF project has successfully increased the component sharing rate because of the design rule. Within the CMF project, USFTs do not have authority to manage strategic issues alone, because engineers were unable to formulate design rules due to strategic factors beyond their control. To resolve this issue, JSCs, with the power to resolve such issues, were established and staffed with General Managers from both Nissan and Renault by the Alliance Directors. The Alliance Directors are the highest decision-making bodies across both companies. The JSCs led the process of RB resolution, improving preconditions for

component-sharing. This organizational system was a completely new approach for Nissan, first adopted for the CMF project.

The development of design rules requires close coordination between departments with a technical perspective and other departments with a strategic perspective during the first stage of the NPD process. Through close coordination and information sharing, technical departments learn strategic perspectives while strategic departments learn technical perspectives. The design rule formulation process is therefore a type of learning process to find solutions to problems through close coordination and adjustments between two different perspectives. Thus, design rule formulation process can be conceptualized as a learning and decision-making process.

Furthermore, when formulating design rules, the involvement of engineers alone is not enough. Executive-level senior managers should be actively involved during the early stages of development. Senior members must lead the design rule formulation to resolve strategic issues. Moreover, the requirement for their active involvement for a longer period, beginning at earlier stages, constitutes a significant change from conventional development processes, where their involvement was limited to early planning stages.

Clearing both the nature and the process of design rule formulation are the paper's second contributions to existing research on modularity.

5.3 Emerging role of new project leaders due to fragility of modular strategy

Modular architecture development requires the addition of project leaders different from the conventional project leader. In a conventional overlapping NPD process, frequent interface changes are likely to be made among the various component development groups. Conflicts over component interfaces are likely to become common. As existing literature shows, management of these conflicts requires heavyweight (HW) project leaders. An HW project leader is like a president residing over an assigned car, which means they are almighty in decision making of every aspect of that car. In the case of Nissan, the CVE play the roles of HW project leaders.

However, the features of HW project leaders do not suit the modular architecture concept, because they tend to focus on improving the quality of their assigned car as much as possible, and may prefer customized above standardized shared components. This may ultimately lead to collapse of the modular concept, accordingly the modular strategy is fragile. To overcome this fragility, a modular strategy requires a person with responsibility to manage interfaces, enforce the design rules, and maximize component sharing. In the present paper, the title of this person is called the module leader

(ML).

Actually, Nissan CMF has established new positions to manage the modular concept of CMF where interface rules and component sharing need to be managed through two dimensions, market segment dimension such as Segment B and big module dimension such as engine compartment big module. The manager of component sharing along with segment dimension is the APFL in CMF. In contrast, the manager of big module dimension is the ABML. The roles of the APFL and the ABML are akin to managing the interface rules and maximizing component sharing in each dimension. In this meaning, both may be regarded as module leaders. Proposing such new project leaders required for modular strategy is this paper's third contribution.

The difficulty facing new project leaders is that conflict will tend to occur between an HW project leader and a Module leader, because their roles and purpose differ. Who should have the most power? At least, a Module leader needs the same power as an HW project leader. Otherwise, the amount of component sharing might decrease and interface rules might change, resulting in collapse of the modular concept. The method of solving this power balance differs among automakers. For instance, German VW required HW leaders to sign a pledge to strictly adhere to the design rules. In this sense, module leaders are more powerful than HW leaders in VW (Nikkei Automotive 2016.1). Also, Nissan CMF gave the same power to APFL and ABML as HW project managers. Nissan resolve conflicts and make decisions, based on consensus building through dialogue and discussion among the three project leaders.

6 Conclusions and implications

In this section, we briefly summarized what has been found here and consider what kind of framework can be derived from that discussion. Then we conclude with its implication on management strategy.

Theoretical consideration and in-depth case analysis of CMF have shown that a modular strategy requires a two-stage NPD process and module leaders that differ from a conventional overlapping process and HW project leaders. The first stage consists of formulating design rules and fixing them. The second stage consists of concurrent development of components, beginning only after the design rules have been formulated. This sequence must be strictly observed, with clear boundaries between these two stages. Because, the design rule formulation stage requires an integrative organizational process across strategic and technical perspectives, which is completely different from the nature of component development in the second stage. Also, not only HW project leaders but module leaders

are necessary to maintain the modular strategy.

Based on this knowledge and findings as a foundation, we can build a framework of effective NPD process in terms of product architecture, that is, which kind of NPD process is effective depends upon its product architecture. Existing literature identified speed of market change as one possible factor influencing the effectiveness of overlapping process and HW project leaders. Overlapping and HW project leaders can be considered effective in stable industries such as the automobile industry, and not effective in fast-changing industries such as the computer industry (Eisenhardt and Tabrizi, 1995). In addition to the rate of market change, this paper proposes another factor influencing effectiveness of overlapping and HW project leaders, that is, product architecture. From this viewpoint, we argue that an overlapping NPD process must be effective for integral (non-modular) architecture, not for modular architecture. Developing modular architecture requires a different type of NPD process and project leaders from overlapping process and HW project leaders. This paper suggests a two-stage NPD process and module leaders as a new type of NPD process effective for modular architecture. Thus, as Table 1 shows, we propose a framework for considering an NPD process in terms of product architecture, which will lead to advancing our understanding of effective NPD process.

Table 1 Product architecture based framework of NPD process and project leader

Product architecture	NPD process	Project leader
Integral (non modular) architecture	Overlapping process	HW project leader
Modular architecture	Two-stage process with clear boundaries between each stage	HW project leader Module leader

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Finally, we would like to touch upon the managerial implication of this research. Based on

discussion and findings so far in this paper, the change of product architecture to a modular product also requires changes in the NPD process. Nevertheless, many modular projects continue to utilize conventional, overlapping NPD processes. This continuation of conventional NPD processes can lead to failure of modular projects, because design rules may be changed during the component development process.

Therefore, the success of product modularity requires engineers to observe a new rule, that, once design rules have been established, subsequent changes are not permitted. Some engineers may strongly resist this rule, because they are accustomed to conventional NPD processes. In conventional processes, problems with interface rules during actual product design are resolved by tracing back through the previous processes. The conventional process adopts less restrictive rules, with design activities beginning during early stages of development and any problems related to interface rules resolved through later collective adjustment. Engineers are accustomed to such a conventional development process, where design specifications are determined during overlapping from earlier stages.

Managers must therefore convince engineers accustomed to the conventional process and resistant to change to adopt the new NPD process. The active involvement of senior managers becomes important, as they must explain to front line engineers the need to adopt a modular strategy and to change away from conventional NPD processes. Actually, in the case of CMF, the chief technical officer (CTO) played an important role in persuading some engineers who insisted on conventional NPD. To persuade engineers, senior managers need deep and precise knowledge on modular strategy.

This paper has tried to clarify the NPD process and role of new project leaders for modularity, in particular the process of development of a design rule. This research is an unexplored area bordering research on product modularity and new product development. Further research is expected in the future, as this paper was based on single case study, that of the Nissan CMF.

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¹ Another example is a different way of thinking about the layout, such as the arrangement of the engine room, seats, persons, and others. This is determined at the first stage of the vehicle production plan by considering various requirements, such as center of gravity, dynamic performance, under-floor arrangement, styling, and performance. This layout is often determined not only from a purely technical viewpoint but from a company's accumulated knowledge and experience.

² According to Nissan's estimates, if the component sharing rate is >75%, product diversity is sacrificed, as the vehicles will be too close in design. However, sufficient volume efficiency for common use requires a component sharing rate of 50%. Therefore, it is important to make judgments in design that balance the rate of shared components, differentiation, and investment within a component-sharing rate of 50% ~ 75%.